SEISMIC CHARACTERISTICS OF THE SHALLOW (0- 1 m) SOILS ON THE MOON AND MARS: ICE IN SOILS.

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Introduction: We highlight a payload concept where piezo-sensors are used to characterize the shallow subsurface (0-1 m) regolith of planetary bodies. Our group's long-term mission is to design a seismology instrument as a promising low-cost, low-risk, high-reward payload candidate to permit non-invasive, high-resolution characterization of the regolith profile. Piezo-technology for testing and measurement is a mature and robust technology with wide use in the defense, aerospace and structural engineering fields.

Water is key for to support future human missions on the Moon as well as Mars, and high-frequency seismic sounding tools have the potential to provide a minimally invasive characterization of the volume and distribution of ice. Unfortunately, for example, as in the case of Mars, current instrumentation deployed in orbit (e.g., Shallow Radar, SHARAD, ~10 m free-space vertical resolution) or planned for rovers (e.g., Mars2020 Radar Imager for Mars' subsurFAce eXperiment (RIMFAX), ~14 cm resolution) does not allow fine-scale characterization of the shallow subsurface via a low-resource platform. Without such resolution, the processes that support the formation of ice as an in situ resource will be difficult to understand, undermining the potential for sustainable resource use by humans.

Piezoelectic Sources and Receivers: Piezoelectric materials have been widely used over the past 100 years, e.g. in radios and sonar. These materials will produce an electric charge when stressed and conversely will change shape when subjected to an electric field. When structurally integrated into the legs (Fig. 1) and wheels (Fig. 2) of planetary landers and rovers, piezoelectric devices have an unexplored potential to act as both as sensors and seismic sources for the underlying shallow soils. Piezoelectric ceramics such as those that comprised the penetrometer on the Huygens lander on Titan were even capable of enduring prolonged exposure to radiation levels [1] during a 7-year mission. As well, piezo-sources can be used to produce high enough frequencies in order to allow a resolution of 1-10 cm (Fig. 3) .

Natural seismic attenuation (Fig. 3) is a critical parameter to seismic interrogation because it limits the distance that high-frequency seismic energy can travel within the soils between source and sensors and still be detected (e.g., Q_P 6 -100; [2]).

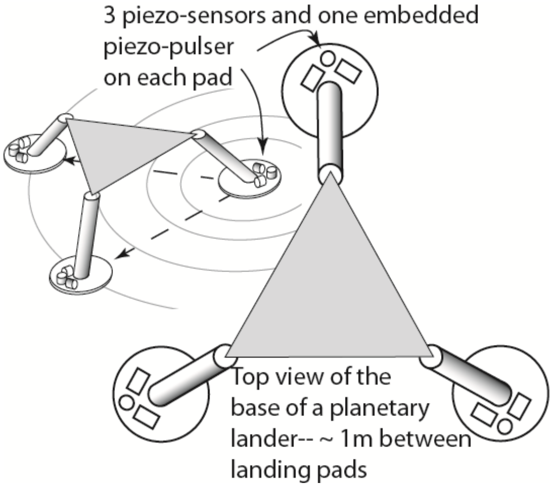

Figure 1. Conceptual planetary lander base envisioned for future research development of piezo-device technology and science.

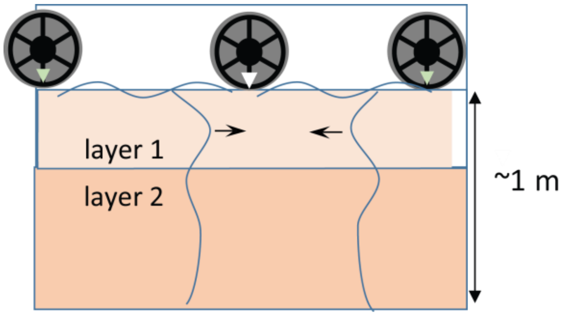

Figure 2. Rover wheel motion can act as an seismic source to surface waves (blue curves). Triangles represent sensors. Different soil layers and soil-ice concentrations can be characterized by surface seismic vibrations (amplitudes, dispersion character, velocity).

Intrinsic seismic attenuation may result from friction between the grains due to variations in size and roundness. Seismic attenuation is often presented in terms of energy stored vs. energy lost per cycle by the seismic quality factor (Q).

Studies of pore-fluid freezing on earth are few (e.g.,[3]) but seismic reflection active-source methods are known to be sensitive to the presence of interstitial frozen ice and the ice-table boundary will be a good seismic reflector.

Soil models can derive from contact theory ([4],[5]) where the general elastic properties (bulk-K_{ref} and shear-G_{ref} moduli) are predicted from a dry pack of a

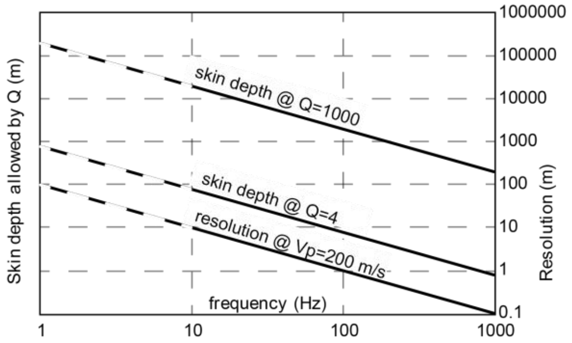

Figure 3 Estimates of effective seismic penetration of surface waves (skin depth), resolution (~wavelength/2) versus frequency content for a 'soft' (=4) and 'hard' (=1000) Quality factor Q (1/intrinsic attenuation). Only 10-1000 Hz cases (NOT dashed) are expected to match piezo-sensor responses. Both axes are plotted show $\log_{10}$ scales.

randomly disordered, stack of spheres under an effective confining stress conditions which incorporates from the overburden weight as well as the effective cohesion between grains (Fig. 4).

If ice is considered to bond grains together, then cemented contact theory [6] in combination with effective medium theory [7] can be used to predict seismic velocities for the full range of ice saturation in the pore spaces:

$V_S = \sqrt{\frac{G_{eff}}{\rho_{eff}}}$ and $V_S = \sqrt{\frac{G_{eff}}{\rho_{eff}}}$,where K_{eff} and G_{eff} are the effective bulk and shear moduli respectively. When the given soil porosity is occupied by a certain fraction of ice the effective density of the medium is ρ_{eff} . Modifications to the basic assumptions such as the actual smoothness of grains and direct grain contact interaction may limit the accuracy of these velocity predictions ([8],[9]).

Contact theory can be modified to include frozen ice in soil pores via cement contact theory [7]. By analogy to the well-known effect of patchy cementation ([10][11]), an extended contact theory predicts that the primary cause of an increase in seismic velocities (from 10^2 m/s to 10^3 m/s) will be the increase in rigidity from the frozen soil.

Expectations: The shallow ice-soil boundary is readily approachable to theory and, using piezo-devices, we can investigate Lunar and Mars reservoirs for H_2O ice that are an area of interest for fundamental science and human exploration.

For the simplest ice-table scenarios where the soil above the ice-table is dry but the porosity below the ice-table is completely saturated with ice we expect a large acoustic impedance contrast (e.g., Fig. 2) Intrinsic attenuation and scattering are expected to be the main limiting physical factors to resolution and penetration.

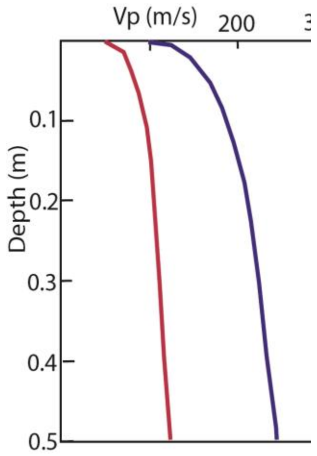

Figure 4 . Theoretically estimated compressional wave (Vp) velocity in shallow soils; derived by using grain size (.5 mm diameter) and density from a Mars JSC-1 DRY soil model [12] [13]. The case for conditions both on Earth (blue) and on Mars (red line) both show an increase with depth, controlled by overburden net load.

We also note that in addition to traditional refraction and reflection arrivals, surface waves have larger amplitudes and may be derived both from active source experiments or self-generated environmental noise such as resulting from rover-wheel motion against soil. Properly characterized and recorded 'noise' can also be inverted for shallow velocity shear wave velocity structure ([14] ,[15]).

References:

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